Fat Replacers and Their Applications in Food Products: A Review

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ABSTRACT

Link of fats to chronic disease in Europe and North America is well established. Overconsumption of high energy-dense foods may contribute to energy imbalance and lead to increasing incidence and prevelance of obesity as well as the risk of chronic diseases.

Fat replacers are used to provide some or all of the functional properties of fat while providing fewer calories than the fat being replaced. They are either fat substitutes or mimetics. Fat substitutes are lipid-like substances intended to replace fats on a one-to-one basis. Fat mimetics are protein or carbohydrate ingredients which function by imitating the physical, textural mouth feel and organoleptic properties of real fats.

Carbohydrate-based fat replacers are derived from cereals, grains and plants, these ingredients include both digestible and indigestible complex carbohydrates. They include starch and fiber-based fat mimetics. The former include maltodextrins, and modified starches, while the latter include microcrystalline cellulose methylcellulose, gums, pectins, hydrocolloid gums and polydextrose. Protein-based fat replacers such as microparticulated whey protein provide structure, viscosity, creaminess and opacity, a clean flavour base with only one-thrid of the calories in fat.

The majority of fat-based fat replacers are emulsifiers or lipid analogs. They are neither hydrolyzed nor absorbed by the body in the same manner as normal fat and thus contribute substantially fewer calories.

Numerous applications of fat replacers have been discussed. The main food commodities being targets in this respect include bakery products (cookies, pound cakes), meat products (beef burger and frankfurter type sausage) dairy products (cheeses, yoghurt and ice-cream) and other products (human milk fat substitute, low-calorie structured lipids and mayonnaise).

Keywords: fat substitutes, emulsifiers, structured lipids, fat mimetics, microparticulated proteins, microparticulated carbohydrates, cookies, biscuits, cakes, frankfurters, milk fat, cheese, yoghurt, ice-cream, mayonnaise.

INTRODUCTION

Link of fats to chronic disease in Europe and North America is well established. Over twenty governments and health organizations from many parts of the world have formulated recommendations asking for a reduction in people's total fat and saturated fat. Although specifics differ by country or health promotion group, all advocate a lowered fat intake in order to reduce the incidence and morbidity of many cancers, coronary heart disease, stroke, high blood pressure, obesity and diabetes (Grossklaus, 1996, ADA, 2005).

Over the past decade, obesity rates have increased by more than 60% among adults, with approximately 59 million adults being obese. Among youth ages 6 to 19 years, approximately 9 million are considered to be overweight (CDCP, 2000). Overconsumption of high energy – dense foods and beverages, and increased portion sizes, may contribute to positive energy balance and lead to increasing incidence and prevalence of overweight and obesity (Swinburn & Egger, 2002). A 10% reduction in the proportion of fat in the diet can result in a corresponding reduction of 238 kcal/day of total energy intake (Astrup *et al*., 2000). Therefore, lowering the fat content of foods by using fat replacers, along with reducing the food's calorie level, has tremendous potential for altering the energy density of certain foods and could potentially have a significant impact on health maintenance (ADA, 2005).

Total energy, total fat, and saturated fat intakes were found to be significantly correlated with the frequency of eating foods and snacks out of the home and with an increased body mass index (BMI) (McCory *et al*., 1999, Thompson *et al*., 2004). Frequent selection of meat items, grain and potato products, and breakfast and late night snacks eaten away from home were associated with higher fat intake and obesity (Gillis & Bar, 2003). Thus, awareness of these patterns is helpful in determining for which foods and in which situation fat replacers might have a role in reducing total fat, saturated fat, and energy intake. Furthermore, fat replacers were developed in response to consumer concern with quantities of dietary lipid and its possible link with obesity (Owusu – Apenten, 2005).

Functional role of dietary fat

Dietary fat is a major energy source, essential for growth and development, and provides essential fatty acids needed for maintaining structure of cell membrane and for prostaglandin synthesis. Also, fat aids in the absorption of fat-soluble vitamins and other phytochemicals (Giese, 1996).

Fat in food has multiple functions during cooking process. Its heat transfer properties enable rapid heating and attainment of very high temperatures. High temperatures achieved by frying and deep-fat frying create many browning (Maillard Reaction) taste components that have positive sensory attributes. Fats absorb many flavour compounds and round the flavour by reducing the sharpness of acid ingredients. In meats, fat carries the flavour and contributes to the juciness and tenderness, key to the difference in taste of the various kinds of meat and poultry (Grossklaus, 1996, Jones, 1996).

Functionally, fats affect the melting point, viscosity and body, crystallinity, and spreadability of many foods (Drewnowski, 1998, Sandrou & Arvanitoyannis, 2000). Fat imparts a velvety mouth feel to products such as ice-creams, desserts, and cream soups. Smoothness in ice-creams and some candies is due to fat preventing the formation of large water or sugar crystals. Fats are responsible for the aroma and texture of many foods, thereby affecting the overall palatability of the diet. Although fat in food may increase acceptance, high-fat foods and diets are also high in calories (Giese, 1996), which may be problematic for the majority of individuals struggling with energy balance.

In baked products, fat inhibits the formation of tough gluten strands, softens the crumb, imparts tenderness and delays staling. Crispines in cookies is due to fat in combination with some of the other ingredients. In flaky products such as croissants and pastries, fat's ability to pool in layer and coat gluten strands is crucial. Thus, fat replacers must be chosen with care to replicate the function of fat (flavour, texture, lubrication, volume/bulk, or heat transfer) to produce an acceptable product. With the aforementioned effects, it is easy to see why fat replacement is challenging and may require a combination of ingredients and changes in processing to produce a product that approximates the full fat product (Grossklaus, 1996, ADA, 2005).

Fat replacers: definition and classification

A fat replacer is an ingredient that can be used to provide some or all of the functions of fat yielding fewer calories than fat. Fat replacers need to be able to replicate all or some of the functional properties of fat in a fat-modified food (Schwenk & Guthrie, 1997). It is worth to mention that the term of fat replacer implies that a substance has certain desirable physical or organoleptic attributes of fats which it replaces without any of the undesirable properties of fats (Hassel, 1993, Martin, 1999). There are several categories of fat replacers, and there is often confusion regarding how the categories are defined. Fat replacers are either fat substitutes or mimetics. Fat substitutes are lipid-like substances intended to replace fats on a one-to-one basis. Fat mimetics are protein or carbohydrate ingredients which function by imitating the physical, textural, mouth feel and organoleptic properties of real fats (Owusu-apenten, 2005).

Fat substitutes are ingredients that resemble conventional fat and oils and can replace fat on a gram-for-gram basis. Because they are fat based, they are often stable at cooking and frying temperatures and provide all the functions of fat while yielding <9 kcal/g, which could be zero calories if non is absorbed.

Fat analogs are compounds with many of the characteristics of fat but have an altered digestibility and altered nutritional value.

Fat extenders optimize functionality of fat, thus allowing a decrease in the usual amount of fat in the products.

Fat mimetics are ingredient that mimic one or more of the sensory and physical functions of fat in the food. They are based on carbohydrate, protein or fat components used alone or in combination and provide from 0 to 9 kcal/g. They provide lubricity, mouth feel, and other characteristics of fat by holding water. The four broad categories of fat replacers are shown in Fig. (1).

Stern & Hermann-Zaidins (1992) described an ideal fat replacer by being safe, physiologically

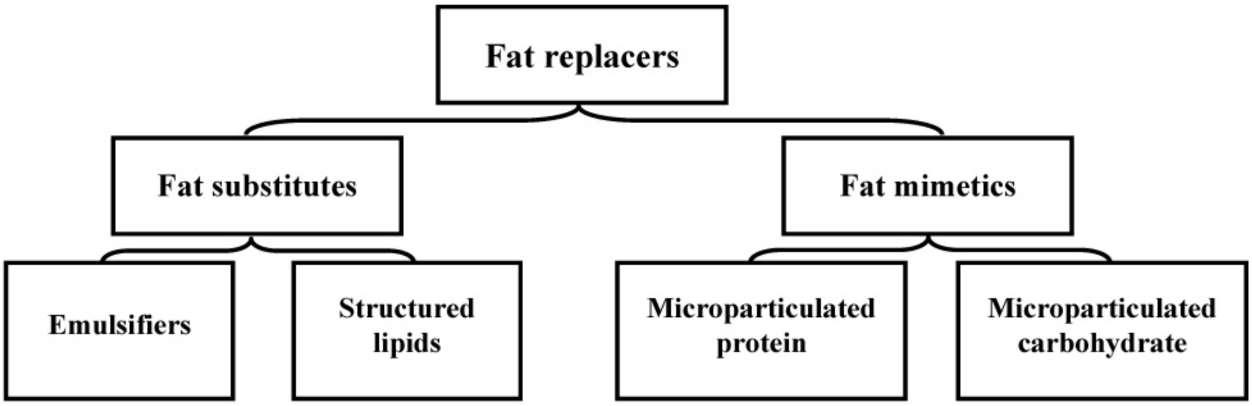

Fig. 1: Classification of fat replacers

Source: Owusu-apenten (2005)

inert, and nutritionally equivalent and creates the illusion of fat content. It should allow heat transfer since fat is heat exchange medium that enables rapid cooking (Jones, 1996).

Fat replacers can be also classified as: 1- Starch derived, 2- Fiber-derived, 3- Protein-based, 4- Gums, gels and thickners, 5- Emulsifiers, 6- Bulking agents, 7- Low calorie fats, 8- Fat extenders, 9- Synthetic fat- substitutes, 10- Combination systems. The aforementioned classification is based partially on chemical composition and partially on functionality of the ingredients, and includes combination systems (i.e. blends) (Jones, 1996).

Tables (1, 2 and 3) give examples of fat substitutes, fat mimetics and fat replacers used in various food categories.

Table 1: Examples of fat substitutes*

Name/group	Composition
Emulsifiers	
Olestra®, Olean®	Sucrose esterified with 6-8 fatty acids
Sucrose fatty acid ester	Sucrose esterified with 1-3 fatty acids
Sorbestrin®	Carbohydrate + fatty acids
Sorbitol – fatty acid ester,	
Alkyl glycoside polyester	Alkyl glucoside + fatty acid
Span® and Tween®	
Miscellaneous	Sorbitan monostearate (Spans),
	Polyoxyethylene fatty acid esters (Tweens)
	Polypropylene fatty acid esters
Structured lipids	
Caprenin®	Medium chain trycyiglycerol (MCT)
	$C_{8:0}$, $C_{10:0}$, $C_{22:0}$
Neobee®	Medium chain trycyiglycerol (MCT) from coconut oil, plam oil
Salatrim/Benefat®	MCT; C2:0 to C4:0. C18:0 fatty acids
Dialkyl dihexdecyl malonate	

® : Registered. Source: ADA (2005)

Table 2: Examples of fat mimetic

Name/group	Composition
Microparticulate protein	
Simplesse®	Microparticulate whey protein, egg protein
Trailblazer®	Microparticulate egg protein, milk protein
Dairylo®	Whey protein
Lita®	Corn gluten
Microstructure carbohydrates and gelling agents	
Avicel®	Cellulose microparticles
Methocel®	Cellulose ethers
Amalean® I & II Farinex,	
Instant Stellar, Perfectamyl AC,	
PURE-GEL®, STA-SLIM	Modified starches
Kel-Lite KELCOGEL®, KELTROL®, Slendid	Xanthum, pectin, alginates and other structural polysaccharides
Oatrim®	Oat derived, forms thermoreversible gels
Slendid	Microparticulated pectin gel particles

Source: ADA (2005)

Table 3: Examples of types of fat replacers used in various food categories

Food category	Fat replacer	
	Carbohydrate-based	Protein-based
Baked foods	Fibers, gums, inulin, maltodextrins, polydextrose, starches	Microparticulated protein, modified whey protein concentrate, protein blends
Cereal and grain products	Fibers, gums, inulin, maltodextrins, polydextrose, starches	Microparticulated protein
Confectionery and candies	Cellulose, gums, inulin maltodextrins, Oatrim[a], polydextrose, starches	Microparticulated protein
Cooking and salad oils	NA[b]	Microparticulated protein
Dairy products	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, modified whey protein concentrate
Dairy products, refrigerated and frozen desserts	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, modified whey protein concentrate, protein blends
Meat and poultry products	Gums, inulin maltodextrins, Oatrim, starches	NA
Other fats and oils	Cellulose, gelatin, gums, inulin, maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, protein blends
Prepared entrees	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, modified whey protein concentrate
Soups, sauces, gravies	Cellulose, gums, inulin maltodextrins, Oatrim, starches	Microparticulated protein, modified whey protein concentrate
Savory snacks	Cellulose, fiber, gums, maltodextrins, starches	NA

[a]Proctor and Gamble, Cincinnati, OH. [b]NA = not applicable.
Source: ADA (2005).

Types of fat replacers

1- Carbohydrate – based fat replacers

Carbohydrate – based fat replacers are derived from cereals, grains and plants, these ingredients include both digestible and indigestible complex carbohydrate (Glicksman, 1991).

Starch – derived fat mimetics:

Maltodextrins are defined by FDA as non sweet, nutritive saccharide polymers consisting of D-glucose units linked primarily by α-1-4 bonds with a dextrose equivalent (DE) of less than 20. The low DE maltodextrins at a DE range of 1 to 10 has been found particularly useful in fat replacement (Roller, 1996). The industrial manufacture of maltodextrins involves first gelatinization of starch at 105°C in the presence of either acid or enzyme to a DE value of <3, followed by jet-cooking at (110-180°C) to ensure complete gelatinization, the starch slurry is cooled and treated with a fresh batch of bacterial α-amylase until the desired degree of hydrolysis is reached (Roller, 1996). The gross chemical composition of maltodextrins is related to the botanical source and can be divided into two broad groups: root starches and cereal starches. The latter group exemplified in potato and tapioca starches are particulatarly attractive for many food applications including fat replacement. They have a low lipid and protein contents as compared to cereal starches which prevent many undesirable properties of starch. They also contain amylose-molecules with longer chains (DP 3000) than those found in corn and wheat starches (DP 800) and are thought to retrograde less readily and thereby reducing the tendency to cause turbidity and undesirable texture (Whistler *et al*., 1984, Swinkels, 1985, BeMiller, 1993). Maltodextrin gels derived from potato starch have plastic, spreadable, shortening-like texture and nonelastic in nature. The gels are thermo reversible i.e. they melt upon heating and reset to a comparable gel strength when cooked down. They are also shear-thinning and reform when shearing is stopped. Low-DE maltodextrins derived from potato starches enhance creaminess provide body and give a fatty mouth coating to the food product in which they are used. The most common applications where low-DE maltodextrins exhibit these functionalities particularly well are cream soups and sauces, frozen desserts low –fat salad dressings and bakery fillings (Harkema, 1996, Roller, 1996).

Modified starches

Their main functions of modified starches are as bodying agents and texture modifiers intended to be used with emulsifiers, proteins, gums and other modified food starches. The main commercial modified starches are Oatrim and Z-trim (Owusu-apenten, 2005).

Oatrim is known also as α-Trim TM, Trim choice. Oatrim produces 1-4 kcal/g. This type of fat mimetics is made by partial enzymatic hydolysis of oat starch. The water soluble products of oat flour are used to replace fat and as a texturizing ingredient. Oatrim is classed as GRAS (generally regarded as safe) by the FDA. This ingredient may be used for baked goods, fillings and frostings, frozen desserts, dairy beverages, cheese, salad dressings, processes meats, and confections (Owusu-apenten, 2005).

Z-trim is an insoluble fiber from oat, soybean, pea and rice hulls or from corn or wheat bran. The mouth feel of Z-trim is similar to fat in terms of its moistness, density and smoothness. Z-trim has the further advantages of increasing the fiber content of food. It has FDA status and can be used with baked goods, burgers, hot dogs, cheese, ice-cream and yoghurt. Despite its heat stability, Z-trim is not considered suitable for frying (Owusu-apenten, 2005).

Fiber based fat mimetics

Microcrystalline cellulose is colloidal products based on co-processing microcrystalline cellulose with sodium carboxymethyl cellulose. A recent addition to the colloidal microcrystalline cellulose products was based on co-processing with alginates or whey or maltodextrin (Humphreys, 1996). These products are readily dispersed and are now used as fat replacers in a myriad of food products. Table (4) shows the key physical and chemical properties of colloidal grades of Avicel (the trade name of microcrystalline cellulose). Usage levels of microcrystalline cellulose can range from 0.1 to 10%, but standard use levels are from 0.4 to 3.0%. The food products where microcrystalline cellulose are most frequently used as fat replacers include: salad dressings, bakery products, dairy products, ice-cream and frozen desserts, cheese spreads and processed meats. The standard usage levels range from 0.4 to 3.0%. In most food systems, microcrystalline cellulose is used as part of an overall fat-mimetic system, which often includes soluble hydrocolloid starch, fat flavours and antimicrobial agents (Humphreys, 1996).

Table 4: Key physical and chemical properties of colloidal grades of Avicel® microcrystalline cellulose

Properties	Avicel® RC501	Avicel® RC581	Avicel® RC 591F	Avicel® CL611	Avicel® RCN30	Avicel® AC815	MicroQuick WC595	MaltoQuick MC230
MCC content (%)	91	89	88	85	75	85	22	22
Process	Bulk-dried	Bulk-dried	Spray-dried	Spray-dried	Co-processed with xanthan and maltodextrin	Co-processed with calcium alginate	Co-processed with whey	Co-processed with maltodextrin
Equipment required to activate	Homogenizer	Homogenizer	High speed mixer	High speed mixer	High speed mixer	High shear or low shear with sequestrantes	Low shear	Low shear
Use levels in food (%)	0.5-3.0	0.3-0.8	0.3-1.0	0.2-2.5	0.5-1.5	0.4-2.5	2.0-4.0	2.0-4.0
Initial viscosity (cP*)	72-168 at 2.1%	72-168 at 1.2%	39-175 at 1.2%	50-151 at 2.6%	620 at 3%	n/a	10-100 at 6%	50-150 at 5%
Set-up viscosity (cP**)	1025 at 2.1%	1125	1250 at 1.2%	1850 at 2.6%	n/a	n/a	1200 at 6%	
Primary uses	Whipped toppings, heat-stable emulsions	Frozen desserts	General stabilizer, thixotropic gels	Pourable systems	Stabilizer, frozen desserts	Stabilizer, dry blended or low shear foods	Dry blended foods	Dry blended foods

Note: MCC = Microcrystalline cellulose.
* Initial viscosity was measured at 120s, using a Brookfield RVT Viscometer No. 1 Spindle at 20 rpm.
** Set-up viscosity was measured at 24 h using a No. 3 Spindle at 20 rpm.
Source: Humphreys (1996).

Methylcellulose gums such as methylcellulose (MC) and hydroxypropylmethyl cellulose (HPMC) are commercially significant polymers used in a variety of food applications for more than 40 years. Like fats, MC and HPMC helps entrain air in food stuffs to improve structure, stabilize air or carbon dioxide bubbles to reduce volume loss and enhance moisture retention (de Mariscal & Bell, 1996). Chemical structures of MC and HPMC are given in Fig. (2).

The most important applications of MC and HPMC include: fried foods, liquid foods, baked products, frozen dairy products and low-fat whipped toppings. The main benefit from using MC and HPMC in fried food products is the reduction in fat uptake achievable during the frying step. This contributes to a lower caloric value and improved cooking economy from reduced oil losses. Also, reduced fat-baked goods have benefited from their use as they compensate for fat removal by enhancing air entrainment, promoting uniform fine cell size in the crumb structure (de Mariscal & Bell, 1996).

Pectin is a hydrocolloid consisting of partial methyl esters of polygalacturonic acid. Pectin is found in all fruits and vegetables and is obtained by aqueous extraction of citrus peel and apple by-products of juice manufacture. The peel or pomace may be blanched after juice extraction in order to inactivate the endogenously located pectin esterases followed by drying (Giese, 1996). There is a range of specially tailored pectins for fat replacement. Commercial pectins are divided into low methoxy (LM) pectins and high methoxy (HM) pectins according to the degree of estrification (DE). The DE is defined as the percentage of galactuoronic acid units that are methyl estrified. Pectins with a DE below 50% are designated as LM-pectins, whereas pectins with DE above 50% are designated as HM-pectins. The DE values for commercial LM-pectins typically range from 20 to 40% and from 55 to 75% for HM-pectins (Nielsen, 1996).

Slendid covers a range of special pectins tailor-made for fat replacement. It offers a range of properties including: stability of heat, pH, shear and salt, neutral taste, fat-like dissipation, virtually no calories and relatively low usage levels i.e. 0.2 to 1.5%. It may be used in a wide range of food applications such as: spreads, mayonnaise and salad dressings, processed meats, ice creams, processed cheeses, soups and sauces, desserts and bakery production, in which fat may be partly or fully replaced (Nielsen, 1996).

(a)

(b)

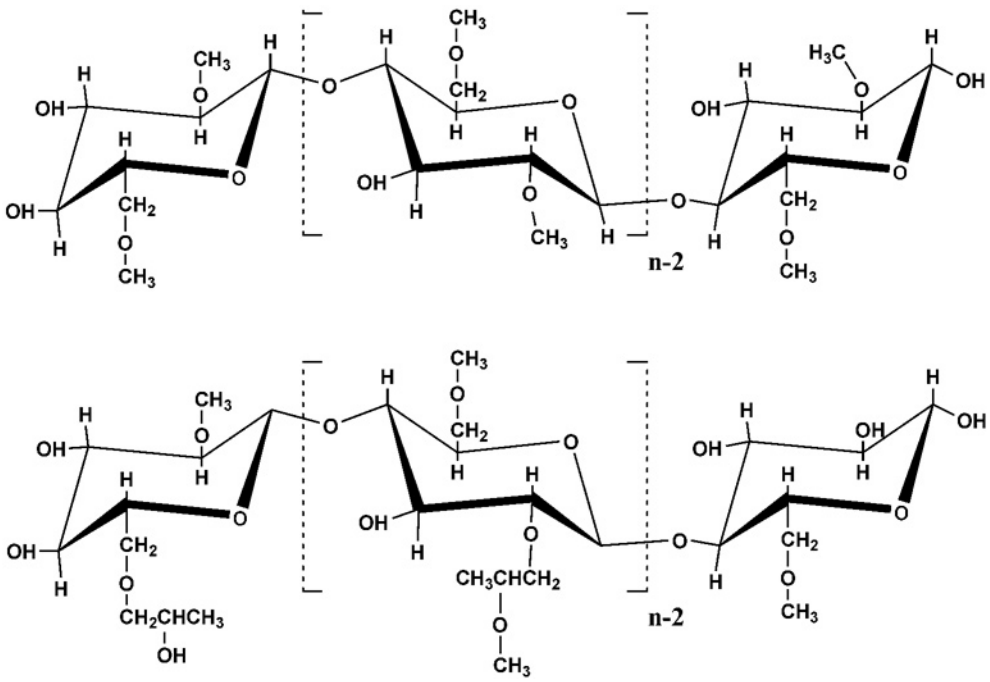

Fig. 2: Typical chemical structures of (a) methylcellulose and (b) hydroxypropylmethylcellulose (Source: Humphreys, 1996)

Hydrocolloid gums are long-chain biopolymer molecules that are obtained from plant materials such as seaweeds, seeds and tree exudates. They may also be produced by the chemical modification of polysaccharides or from microbial fermentation (Giese, 1996). They play a significant role in foodstuffs since ancient times on account of their texturizing and water-structuring properties. It is the high molecular weight of these ingredients, combined with the restrictions in flexibility between monomer units within the polymer chain that gives rise to their viscosifying properties (Clegg, 1996).

The most hydrocolloid gums that can be used as fat mimetics include galactomannons extracted from guar gum and locust bean gum. The role of hydrocolloid gums in fat replacement is not as a direct fat mimetic but as a tool for controlling viscosity and texture and binding excess water in their three dimensional network structure (Clegg, 1996).

Polydextrose is a complex carbohydrate formed by the random polymerization of glucose, sorbitol and citric acid, which has been used in human food as a low-caloric bulking agent (1 kcal/g) since the early 1980s (Mitchell, 1996). Polydextrose, being a multifunctional food ingredient can be also used as a humectant, texturizer, thickner, stabilizer and cryoprotectant.

It is worth to mention that although polydextrose is not a fat-replacer perse, it has a relatively high viscosity in solution and can therefore contribute to the mouth feel and creaminess of fat-reduced formulations. Polydextrose can therefore be considered as a fat-mimetic in some applications such as reduced – fat pastry, soft chewy candies and spoonable and pourable dressings (Mitchell, 1996).

Fruit and fruit pureés can be effective as fat mimietus. Pureé of banana, plums, pears, avocado and apples can perform many of the functions of fat due to their pectin, fiber and sugar content. In particular, the complexes of fiber and pectin provide texture and body. Fruit sugars provide additional solids and water-binding. Added health benefits may include antioxidant activity. Manufacturers have resolved issues with colour by using new spray-drying techniques to produce cream-coloured powders. These replacers may partially or completely replace fat in cookies, muffins, cakes and other bakery mixes. Since these replacers are not modified to the extent others are, their addition must be carefully managed on a case-by-case basis (Pszczola, 2003 and Wekwete & Navder, 2005).

2- Protein – based fat replacers

Protein-based fat replacers are derived from milk, egg, whey or vegetable proteins. These include such ingredients as microparticulated protein as well as refined whey and soy proteins (Giese, 1996).

Microparticalated proteins

A patent process known as microparticulation was used to produce a protein-based fat replacer (Singer & Moser, 1993, CCC, 1996). Microparticulated protein (MPP) contains milk and/or egg or whey proteins (WPC) shaped into small round particles which are perceived by the mouth as creamy. It functions as a surrogate dispersed phase, replacing the fat droplets which conventioinally provide dispersed phase functions which resemble systems as creams, mayonnaise, chocolate frankfurters and pasta. The (MPP) is digested as a protein with reduced calories and no cholesterol. One gram of (MPP) has approximately one-third of the calories of full calorie fats (Singer, 1996).

The MP3 is one of MPP and was the first commercially used in the fat-free ice-cream. Internationally, MP3 has been used to produce a fat free butter spread in Ireland and line of fat-free frozen desserts in Finland. In the last decade, it has been reported that MP3 has been effectively applied in the production of low-fat baked goods (Singer, 1996).

Microparticulated proteins cannot be used in high-temperature frying, however, it may be used in most applications requiring heat, including canning, pasteurization and ultra-high temperature processing. It is used in dairy products and the production of cheeses, ice-cream, butter and sour cream as well as in oil-based products such as salad dressings and margarine. It has been designated as GRAS by the FDA for use in frozen desserts type products. The FDA has also agreed that whey-based microparticulated protein conforms to its definition of whey protein concentrate, as GRAS substance (Cheung *et al*., 2002). The microparticulated proteins include Simpless® and Dairy-Lo®.

Simpless® is made from whey protein or milk and egg protein. It produces from 1-4 kcal/g. The manufacturing process involves simultaneous heating and shearing to produce small particles of coagulated protein. It provides the mouth feel of fat. It is not suitable for frying but is stable for baking. It is considered GRAS by FDA and may be used in dairy products, salad dressing, margarine and mayonnaise-type products, baked goods, coffee creamer, soups and sauces (Owusu-apenten, 2005).

Dairy Lo® is a protein-based ingredient which produces 4 kcal/g. It is manufactured via thermal denaturation of proteins from sweet whey. It improves the texture, flavour stability of low-fat foods. It provides the mouth feel of fat and has GRAS status by FDA (Owusu-apenten, 2005).

3- Fat based fat replacers (fat-substitutes)

These are either triacylglycerols with tailored configurations to reduce their caloric content, or they have chemical structures similar to triacylglycerols but reduced or zero caloric content. The fat substitutes are intended to replace the functionality of natural fats on a one-to-one weight basis (Owusu-apenten, 2005).

Emulsifiers

These are partial esters of fatty acids with chain lengths from C12 to C22 and polyvalent alcohols like glycerol, sorbitol / sorbitan, and sucrose or organic acids like lactic acid. Partial esters may also be estrified with organic acids such as acetic, citric, diacetyl tartaric or succinic form a wide range of esters (Flack, 1996).

Emulsifiers possess many of the properties of fats and oils as exemplified in the fatty consistency, lubricity, and the texture and cohesiveness of fat, they form films or spread on surface, build or increase viscosity through hydration, and soften or weaken structures created by polysaccharides or proteins (Flack, 1996).

Because of their use restrictions and also because they have the same caloric values as fat, their role as fat replacers is in stretching the functionality of low fat levels and in replacing the functionality of fat when used in combination with other ingredients (Giese, 1996). Typical examples of products in which proportions of fat can be reduced significantly by 30% or higher, include yellow fat spreads, biscuits, cakes, baking emulsions, ice cream and salad dressings (Flack, 1996).

Olestra, is an emulsifier produced by reacting sucrose with 6-8 moles of C12–C22 fatty acids in the presence of a catalyst. The chemical configuration of Olestra accounts for its indigestibility and why it does not provide calories. It replaces the glycerol molecule with sucrose and has either 6-8 fatty acids attached. With this many fatty acids, digestive enzymes can't get to the sucrose center in the time it takes for the molecule to move through the digestive tract. The sucrose center is where the breakdown of the substance for absorption into the body would take place (Giese 1996, FDA, 2003).

Olestra was approved in 1996 by FDA as a direct human food additive in salted snacks and crackers. It is also used to substitute 100% of fats and oils in the preparation of savory snacks (chips, crisps, extruded snacks and crackers). These uses include the substitution for fat for frying as well as sources of fat in dough conditioners, oil sprays and flavour (Owusu-apenten, 2005).

Sobestrin is produced by attaching a hydrophobic fatty acid to hydrophilic sugar alcohols mainly sorbitol. Other polyols used for sugar-fatty acid esters include tetrahalose, raffinose and stachyose (Owusu-apenten, 2005).

Structured lipids

Structured lipids (SLs) are triacylglycerols (TAGs) that have been modified to change the fatty acid composition and/or their positional distribution via interestrificatin in glycerol backbone. The SLs provide an effective mean for producing tailor-made lipids with desirable physical and chemical properties and/or nutritional benefits. The SLs are produced either by chemical or enzymatic inter-estrification or via genetic engineering (Iwasaki & Yamane, 2000, Osborn & Akoh, 2003, Nielsen *et al*., 2004, Agyare *et al*., 2005).

The medium chain triacylglycerols (MCTs) differ from natural fats by their relative absence of long chain fatty acids. The MCTs can be synthetized by interestrification process. They have lower melting points, high solubility in water and are resistant to oxidation. They are not transferred to the body's store of adipose tissue but are metabolized directly in the liver. There are two products belonging to MCTs, namely Salatrim and Caprenin.

Salatrim, is a structured lipid (short and long acyl triacylglycerol rearranged molecules) produced from a mixture of short chain (C2:0 – C4:0) and a long chain fatty acid (C18:0). The short chain acid are esterified at positions 1,3 of the glycerol molecule. Whereas, the long chain acid is estrified at position 2. Salatrim is also called Benefat, provides approximate 5 kcal/g because the short acids provide few calories whilst stearic acid is only partially absorbed in the body. It is usable at pH 3-7.5 and under cold conditions. The suitable product categories for salatrim include confectionery, cookies, cakes, brownies and pie crust (Owusu-apenten, 2005).

Caprenin, the second product belonging to MCTs, the glycerol back bone is substituted by caprylic acid (C8:0), capric acid (C10:0) and behenic acid (C22:0). This fat replacer yields 5 kcal/g as compared to 9 kg/g for normal fat. The caloric reduction is apparently due to the less efficient metabolism of C8:0 and C10:0 fatty acids within the body. The functional properties of Caprenin are similar to those of cocoa butter. The useable temperature for Caprenin is <132°C and it is especially suited for confectionery products (Giese, 1996 and Owusu-apenten, 2005).

Some applications of fat replacers:

Bakery products

The physical and sensory properties of chocolate-chip cookies made with vegetable shortening and protein-based, lipid-based and carbohydrate-based fat replacers at 50 and 75% replacement have been studied by Armbrister & Sester (1994). Results indicated that all shortening-reduced cookies had significantly less surface cracking, fewer surface protrusions, more uniform but larger cells and more mouth coating.

Sanchez *et al*. (1995) prepared low-fat short bread cookies using combinations of carbohydrate-based fat substitutes at different levels. Data indicated the presence of higher moisture content, greater toughness and lower specific volume with minimal differences in cookie breaking strength as compared to control samples.

Three carbohydrate based-fat replacers were used in biscuits while shortening was reduced at 33, 66 and 100%. The results showed that the fat replacer usage produced significant increase in moisture content, light crust colour, variation in volume and crumb firmness (Conforti *et al*., 1996).

Swanson (1998) used three carbohydrate-based fat replacers to replace 75% of the butter in three peanut butter cookies formulas. Data showed that all reduced fat cookies were rated significantly less acceptable but not rejected compared to control cookies, but there was a trend towards greater acceptability of the cookies prepared with polydextrose.

Two selected types of carbohydrate-based fat replacers derived from potato starch and citrus peel known respectively as Paselli SA2 (P-SA2) and Slendid 100 (S100) were used to replace shortening in two types of bakery products (oriental cookies "Gourayeba" and pound cakes). The fat replacers were applied at 25, 35 and 45% for the former and 40, 50 and 60% for the later. Results revealed that the addition of P-SA2 at all levels did not affect the sensory scores and products were highly scored as the full-fat control samples. The mechanical properties of the tested bakery products as measured by the structograph showed that replacement with P-SA2 for both cookies and pound cakes exhibited lower breaking strengths than the same products with S100 (Shaltout *et al*., 2004).

Wekwete & Navder (2005) investigated the effect of avocado pureé as a fat replacer on the physical, textural and sensory properties of oat meal cookies. Results indicated that cookies with 50% replacement with avocado pureé had significantly reduced spread and water activity as compared to control. Texture analysis showed avocado substitution to significantly decrease cookie hardness and brittleness. Sensory evaluation indicated that the fat-reduced avocado were found to be more soft, chewy and had rounded contours with considerably less surface cracking, less accepted than control but had room for improvement. The 50% replaced cookies with avocado pureé provided 35% less fat and 13% fewer calories compared to control.

Agyare *et al*. (2005) showed that the addition of shortening to soft wheat flour dough resulted in a significant ($P<0.05$) decrease in dough resistance to deformation (P), dough extensibility (L) and dough baking strength (W), suggesting a less developed gluten network. The Salatrim (SL) substitution for shortening did not affect (P) and (W). The cookies incorporating SL at 50 and 75% substitution were significantly similar ($P<0.05$) to the shortening control cookies in both baking and textural qualities.

Bubble and pore formation of a high-ratio cake formulation with polydextrose as a sugar-and-fat-replacer were investigated by Kocer *et al*. (2007). The physical properties were studied by the Imaging technique. Results indicated that polydextrose substitution in the high-ratio cake system had superior properties in distributing the gas phase into the cake batter as indicated by decreasing the average bubble sizes and increasing bubble size uniformity as the level of polydextrose increases. A decrease in the average pore size and pore size uniformity of the cake crust due to the combined effect of reduced batter stability and interference with the gelatinization mechanism was also observed. The resulting high cake system exhibited 22% reduction in calorific value based on total sugar and fat content.

Fat replacers including amylodextrin gels, Simpless® 730 and soybean paste effectively replaced fats up to 75% in cupcakes and 50% in Sablé type cookies without affecting both keeping quality and sensory properties. Moreover, the bioassay experiments evaluating total cholesterol, HDL-cholesterol and triacylglecerol level showed positive effects for rats fed the aforementioned products (Abd-El Khalek, 2007).

Meat products

The effect of fat content and carbohydrate fat-replacers on the release of volatile odour compounds from beef burgers salami and frankfurter has been investigated (Chevance *et al*., 2000). Data exhibited that the reduction in fat content in any of the aforementioned three meat products resulted in a tendency towards an increase in the quantities of volatiles released in the head space. Thus, the addition of carbohydrate fat-replacers such as tapioca starch, maltodextrin and oat fiber to low-fat meat product could assist the flavour qualities of these products by slowing down the release of odour compounds.

The effects of fat level (5, 12 and 30%) and maltodextrin on emulsion stability, cook loss, colour, texture and sensory characteristics of frankfurters were investigated by Crehan *et al*. (2000). Results showed that maltodextrin addition caused a significant decrease in cook loss of the frankfurthers but also decreased the emulsion stability. No significant difference in hardness, gumminess and chewiness values when maltodextrin was present in the reduced fat (5 and 12%) frankfurters were observed. Saltiness, overall flavour intensity, overall texture and overall acceptability were unaltered by maltodextrin. The results indicate that maltodextrin can be used as a suitable fat replacer since it offset some of the changes brought about by fat reduction, decreasing cook loss and maintaining a number of textural and sensory characteristics of the frankfurters.

Hoffman & Mellett (2003) observed that trained taste panels could not distinguish between ostrich meat patties containing either 10% pork lard or 10% of a modified starch/protein isolate (fat replacer) mixture. It was concluded that fat replacers can be used successfully for the production of low-fat ostrich patties without any negative quality attributes being perceived.

The effect of a short chain fructooligosaccharides on the sensory properties of conventional and reduced fat cooked meat sausages has been studied in products in which a fat reduction of close to 40% was obtained. The fibre assayed was used in sufficient amounts to constitute between 2 and 12% of the final product. The results showed that the sensory and textural properties and the overall acceptability were very good, which indicated that this fiber can be considered a promising fat replacer in meat products thus a reduced calorie product enriched with soluble dietetic fiber may be obtained (Cáceres *et al*., 2004).

Cengiz & Gokoglu (2005) studied the changes in energy and cholesterol contents of frankfurter type sausage with fat reduction and fat replacer addition. Fat content of sausages were reduced from 20 to 10% and 5%. Citrus fibers (CF) and soy protein concentrate (SPC) were added at the rates of 2% as fat replacers. The addition of fat replacers content by 38.6% and 45.7%, respectively with no significant differences between sausages treated with CF or SPC.

Dairy products

Functionality of modified tapioca starch and lecithin as fat mimetics in feta cheese was studied. Cheeses were made with no fat mimetics, 1% modified tapioca starch, 0.2% lecithin, and a combination of 0.5% tapioca starch and 0.1% lecithin. Low-fat feta cheeses (9-16% fat) were prepared from bovine 1.6-2.2% fat milk. Cheeses were ripened for 45 days before chemical, sensory, Scanning Electron Microscope (SEM) and texture evaluations. The results indicated that the combination of modified tapioca starch and lecithin improved flavour, texture and overall acceptability of reduced – fat and low-fat feta cheeses (Sipahioglu *et al*., 1999).

Aime *et al*. (2001) used sensory and instrumental analysis to evaluate the texture of regular (10%), light (5%), low fat (2.5%) and fat free vanilla (0.4% ice-creams. The light low-fat and fat-free ice-cream were prepared using a modified pea starch as the fat replacement ingredient. Two processing trials with continuous commercial-like process conditions were undertaken. The trained sensory panel rated the low-fat and fat-free ice-creams to have lower viscosity, smoothness and mouth coating properties. Instrumentally determined apparent viscosity data supported the sensory data. The use of modified starch as a partial fat replacer in vanilla ice–cream was highly acceptable.

Koca & Metin (2004) examined the textural, melting and sensory properties of low-fat fresh Kashar cheese (70% fat reduction) produced by using two protein-based fat replacers (1% w/w simplesse®-D-100 and 1% w/w Dairy-LoTM) and a carbohydrate based fat replacer (5% w/w Raftiline® HP)- during the storage period for 90 days. Results showed that Simpless® D-100 corrected all appearance defects determined in low fat cheese. Both simplesse® D-100 and Raftiline® HP produced an improving effect on flavour, texture and overall acceptability of low-fat cheese until the 30th day of storage. The use of Raftiline® HP caused a slight increase in meltability. These results indicated that both simpless® D-100 and Raftiline® HP can improve the texture and sensory properties of low-fat fresh Kasher cheese.

The physical, chemical, textural and sensory properties during storage of strained yoghurt, a semisolid product made from yoghurt by removing some part of its serum, made from milk with 0.5% and 2% fat and including Dairy-LoTM and Simpless® were analyzed at the first, 7th and 14th day. The sample with lower fat content exhibited higher titratable acidity, ash, viscosity, and colour (L and a-values) than the samples with higher fat content. Dairy-LoTM added samples had higher titratable acidity, fat, ash, viscosity, a-value, flavour, appearance and colour than simplesse® added samples (Yazici & Akgun, 2004).

Calleros *et al*. (2004) determined the flow and creep compliance properties of reduce-fat youghurt containing whey protein concentrate (WPC), microparticulated whey protein, or a blend of both fat-replacers and compared to those exhibited by a full-fat yoghourt (FFY). The results indicated that yoghurt made with WPC showed flow and viscoelastic properties that resembled more closely those of the FFY.

The textural and sensory properties of 3-month-old low-fat cheddar cheeses manufactured with a β-glucan hydrocolloidal composite denoted as "Nutrim", a nutracceutical fat-replacer, were studied. The low-fat control cheeses (11.2% fat) were compared with Nutrim I (6.8% fat) and Nutrim II (3.47% fat) cheeses. The hardness, fracturability, and melt-flow index time values of Nutrim cheeses were significantly lower than the low-fat control cheeses. The elasticity and the cohesivness values were similar for all cheeses. Most textural attributes from the sensory panel were similar, except for Nutrim II cheeses. For flavour attributes, the low-fat control cheeses were significantly less bitter, more buttery and less starchy than the Nutrim cheeses which were less acceptable but not rejected (Konuklar *et al*., 2004).

Kavas *et al*. (2004) manufactured full-fat and low-fat white pickled cheeses by the traditional procedure from bovine milk. Results indicated that the moisture and total nitrogen values of the low-fat white pickled cheeses significantly increased whereas total solids, salt, pH and acidity values of cheese were not affected by the fat-replacers in the cheese milk used. Sensory properties of cheese were adversely affected by the use of fat replacers in cheese making. From the rheological point of view, all the low-fat cheeses containing fat replacers were different from the full-fat cheeses, but no off-flavour or bitterness was noted in any full or low fat cheese.

Zisu & Shah (2005) studied the influence of exopolysaccharides (EPS), pre-acidification and use of two fat replacers FR1 and FR2, on the textural and functional characteristics of Mozzarella cheeses. Control cheeses made with EPS producing Streptococcus thermophilus 285 had the lowest moisture (52.84%) and yield, while hardness and melt properties of these cheeses improved with storage. Addition of FR1 exhibited the greatest stretch and melt than FR2. Pizza bake performance was improved with FR1 than FR2. Coating cheese shreds with oil was necessary for adequate browning.

Other products

Yang *et al*. (2001) applied enzymatic synthesis of low calorie structured lipids (ex. Salatrim) in a solvent-free system. The process was undertaken by transesterification between triacetin and stearic acid using immobilized lipase. Stearic acid (C18:0) was incorporated mainly into the sn-1 and/or sn-3 position of triacetin by lipase–catalyzed reaction. However, when C18:0 was located at the sn-2 position on traiacylglycerol (TAG), the resultant sn-2 monostearin after hydrolysis by pancreatic lipase was well absorbed. On contrary, the free fatty acids released from the sn-1 or sn-3 position on TAG tended to be poorly absorbed. These suggest that the stereo-position of long-chain saturated fatty acids is important in calorie intake.

Nielsen *et al*. (2004) produced a human milk-fat substitute from lard and soybean oil fatty acids by enzyme technology. Structured lipid human milk–fat substitute (SL-HMFS) was compared to commercial human milk fat–substitute (HMFS) regarding fatty acids composition content of anti-oxidant and oxidative stability. Fats were stored at 6°C for four days and the oxidative stability was evaluated. Results indicated that the SL-HMFS had a lower oxidative stability than did commercial HMFS products or lard, probably due to a lower level of tocopherol in SL-HMFS.

Worrasinchai *et al*. (2006) investigated the application of β-glucan prepared from brewer's yeast as a fat-replacer in mayonnaise. Fat was partially substituted by β-glucan (RF) at levels of 25, 50 and 75% which were referred to as 25β, 50β or 75β formulations, respectively, together with a control sample (FF) containing 100% oil without β-glucan. Data indicated that all RF mayonnaise had significantly lower energy content, but higher water content than their FF counter part as the level of β-glucan increased. The pH values of the RF samples decreased as the level of substitution increased, after 2 months storage. The 50β and 75β formulations showed similar firmness and adhesiveness values as those of the FF sample. The microstructure assessed by Scanning Electron Microscope (SEM) revealed close packing structures of large droplets for the FF and 25β. Both FF and RF mayonnaises exhibited thixothopic shear thinning behaviour under steady shear tests. The RF mayonnaise exhibited higher storage stability than FF sample. Sensory evaluation demonstrated that up to 50β formulations were accepted.

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بدائل الدهون وتطبيقاتها في المنتجات الغذائية: استعراض مرجعي

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من المعروف في أوروبا وأمريكا الشمالية وجود ثمة علاقة بين الدهون والأمراض المزمنة، وتفسر هذه العلاقة بأن الإفراط في استهلاك الدهون عالية الطاقة يؤدي إلى حدوث خلل في الطاقة وهو الأمر الذي يؤدي إلى زيادة الإصابة بالسمنة ومن ثم زيادة عامل المجازفة للإصابة ببعض الأمراض المزمنة المرتبطة بالسمنة.

تستخدم بدائل الدهون بغية الحصول على بعض الصفات الوظيفية للدهن وكذا إنتاج قدر محدود من السعرات أقل مما تعطيه الدهون التي يتم استبدالها. وبدائل الدهون إما أن تكون للإحلال أو المحاكاة. وبالنسبة للمركبات التي تستخدم للإحلال فإنها تشبه الدهون ويتم إحلالها على أساس وزن بوزن. أما المركبات التي تستخدم بغرض المحاكاة فهي إما أن تكون بروتينية أو كربوهيدراتية ويتأتى فعلها من قدرتها على مضاهاة أو محاكاة بعض الصفات الوظيفية للدهون مثل بعض الصفات الفيزيقية والقوام في الفم وكذا بعض الصفات الحسية.

وتحضر بدائل الدهون المشتقة من الكربوهيدرات من الحبوب والنباتات، وهي تشمل الكربوهيدرات المركبة (سواءً كانت قابلة أو غير قابلة للهضم) والنشا، ومحاكيات الدهون من الألياف. ويندرج تحت الأولى كل من المالتودكسترينات والنشويات المحورة، في حين تشتمل محاكيات الدهون من الألياف على السليلوز، والصموغ، والبكتين، والصموغ الغروية عديدة الدكستروز (بولي دكستروز). أما بدائل الدهون من البروتينات فتشتمل على بروتينات شرش اللبن وهي تكسب صفات كاللزوجة، والكريمية، والنكهة المرغوبة، في حين أنها تعطي ثلث السعرات فقط الناتجة من الدهون. وغالبية بدائل الدهون عبارة عن مستحلبات أو شبيهات دهون، وهي لا تتحلل ولا تمتص في الجسم بواسطة مسارات الدهون العادية ومن ثم ينتج عنها قدر أقل من الطاقة.

هناك العديد من التطبيقات التي يمكن استخدام بدائل الدهون فيها، ومن أهمها المخبوزات (الكوكيز، الكيك)، منتجات اللحوم (البرجر، السجق) ومنتجات الألبان (الجبن، والأيس كريم، والزبادي) ومنتجات أخرى (بدائل اللبن البشري، الليبيدات منخفضة السعرات – المايونيز).